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SPECIFICATION

BURST SIGNAL EXTINCTION RATIO CONTROL CIRCUIT AND INTEGRATED
CIRCUIT THEREOF, BURST SIGNAL EXTINCTION RATIO CONTROL
5 METHOD, COMPUTER PROGRAM, AND LASER DIODE DRIVE CIRCUIT

TECHNICAL FIELD

The present invention relates to a burst signal
extinction ratio control circuit for controlling an
10 extinction ratio of a laser diode used in optical
transmission of digital data in packet communications and
an integrated circuit thereof, a burst signal extinction
ratio control method, a computer program, and a laser diode
drive circuit.

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BACKGROUND ART

FIG. 4 shows typical characteristics of a laser diode
used for performing optical transmission of digital data in
packet communications. A horizontal axis represents a
20 current I_d flowing through the laser diode, and a vertical
axis represents optical output power P_{out} from the laser
diode. Line A represents characteristics at a given
temperature. When I_d is gradually increased from 0,
initially the optical output power P_{out} is hardly increased.
25 However, the optical power P_{out} starts increased relatively

linearly from the point (point X) on which the threshold current value is surpassed. For conversion a digital electrical signal to an optical signal, this linear region is used. Therefore, when "L" is transmitted, a bias current
5 Ib is applied; and when "H" is transmitted, a modulation current Im is applied in addition thereto. Thereby, the optical output power becomes PL in the case of "L", and becomes PH in the case of "H."

Here, an extinction ratio is defined as PH/PL .
10 Further, when a mark ratio of a digital signal (a ratio of "1" among a plurality of bits) is 0.5, average output power (also referred to as average optical power) is expressed by $(PH+PL)/2$.

However, when characteristics become line B due to
15 temperature changes and changes over time, the bias current Ib and the modulation current Im needs to be changed to Ib' and Im' as shown in the figure in order to equally maintain the extinction ratio and the average optical power. Control circuits for controlling the constant extinction ratio and
20 the constant average optical power as above have been already suggested.

FIG. 5 shows a first construction example of a conventional control circuit shown in Japanese Unexamined Patent Application Publication No. H03-209890 and the like.
25 In FIG. 5, in addition to a control circuit 5, a laser diode

512, a modulation current source 515, a bias current source 516, and a monitor photodiode 511 for converting section of light of the laser diode 512 to an electrical signal are shown. During burst output, a switch 513 becomes connected and a
5 bias current I_b is always applied to the laser diode 512. During the burst, in the case that data is "L," only the current I_b is applied to the laser diode 512; meanwhile, in the case that data is "H," a switch 514 becomes connected, and currents I_b and I_m are applied to the laser diode 512.
10 In reality, pre-bias operation to make the switch 513 connected slightly before starting burst is often performed. However, since this pre-bias operation is not directly related to the invention, explanation thereof is omitted.

When an optical burst signal is sent from the laser
15 diode 512, part thereof is converted to a current by the monitor photodiode 511. This current signal is converted to a voltage signal by a current-voltage converting section (I/V) 51. A maximum value detecting section 52 and a minimum value detecting section 53 respectively detect the maximum
20 value and the minimum value of the voltage signal. An I_m/I_b controlling section 54 obtains the modulation current I_m and the bias current I_b so that these values correspond with P_H and P_L in FIG. 4, and sets these values in the modulation current source 515 and the bias current source 516. As above,
25 control has been made so that the extinction ratio becomes

constant.

FIG. 6 shows a second construction example of a conventional control circuit shown in Japanese Patent No. 2932100 and the like. In FIG. 6, in addition to a control
5 circuit 6, a laser diode 612, a pilot current source 614, a modulation current source 615, a bias current source 616, and a monitor photodiode 611 for converting section of light of the laser diode 612 to an electrical signal are shown. In the case that data is "L," a switch 613 is opened, and
10 currents I_b and I_p are applied to the laser diode 612. In the case that data is "H," the switch 613 becomes connected, and currents I_b , I_m , and I_p are applied to the laser diode 612.

A sine wave signal is output from a pilot oscillator
15 64. As a frequency thereof, a value sufficiently lower than a frequency band of the data is selected. According to the sine wave signal, the pilot current source 614 applies the sine wave current I_p . An amplitude thereof shall be smaller than of the modulation current I_m .

20 When an optical signal is sent from the laser diode 612, part thereof is converted to a current by the monitor photodiode 611. A current signal thereof is converted to a voltage signal by a current-voltage converting section 61. This electrical signal includes a frequency element of the
25 data and a pilot signal. A low-pass filter 62 extracts only

the pilot signal therefrom. A controlling section 63 decides the modulation current I_m and the bias current I_b so that an amplitude of this pilot signal becomes constant. The controlling section 63 has a role for maintaining
5 constant average optical power of the laser diode 612. Therefore, the electrical signal before passing the low-pass filter 62 is also input. When the amplitude of the pilot signal and the average optical power are constant, the constant extinction ratio can be maintained.

10 However, in the foregoing conventional first control circuit, when a data transmission rate becomes fast, high speed operation is required for the monitor photodiode 511, the current-voltage converting section 51, the maximum value detecting section 52, and the minimum value detecting
15 section 53 as well. That is, a bandwidth capable of correctly tracing an optical wave shape generated from the laser diode 512 is required. This leads to a problem that an optical module on which the monitor photodiode and the laser diode are mounted and a control circuit become
20 complicated and their costs become high.

 Further, in the foregoing conventional second control circuit, only the low frequency pilot signal and the average optical power are dealt. Therefore, high speed characteristics of the circuit are not required. However,
25 transmission data is premised on being continuous.

Therefore, there is a problem that the extinction ratio cannot be controlled for the burst signal wherein the signal is intermittent. Further, there is a problem that the pilot signal becomes noise to the data signal, which lowers the transmission quality.

DISCLOSURE OF THE INVENTION

It is an object of the invention to provide an excellent control circuit capable of resolving the foregoing conventional problems, and controlling a constant extinction ratio in relation to a high speed burst signal.

In order to resolve the foregoing problems, in the invention, a function for only slightly increasing a modulation current in units of burst is provided. Control is made so that a difference between average optical power in the case of a regular modulation current and average optical power in the case of increasing the modulation current corresponds with a reference value. Further, control is made so that average optical power in the case of the regular modulation current corresponds with a reference value.

That is, according to the invention, a burst signal extinction ratio control circuit for supplying a control signal to a driving section for performing driving by supplying a laser diode with a bias current and a modulation

current, comprising:

a measurement means for measuring average optical power for each burst of the laser diode;

a modulation current control means for controlling a
5 modulation current I_m of the laser diode based on the average optical power measured by the measurement means; and

a bias current control means for controlling a bias current I_b of the laser diode based on the average optical power measured by the measurement means is provided.

10 According to this construction, the constant extinction ratio can be obtained in relation to the high-speed burst signal at a small cost, and the transmission quality is not degraded.

Further, according to the invention, a burst signal
15 extinction ratio control method for supplying a control signal to a driving section for performing driving by supplying a laser diode with a bias current and a modulation current, comprising:

a measurement step for measuring average optical power
20 for each burst of the laser diode;

a modulation current control step for controlling a modulation current I_m of the laser diode based on the average optical power measured by the measurement step; and

a bias current control step for controlling a bias
25 current I_b of the laser diode based on the average optical

power measured by the measurement step is provided.

According to this construction, the constant extinction ratio can be obtained in relation to the high-speed burst signal, and the transmission quality is not
5 degraded.

Further, according to the invention, a computer program for making a computer execute a burst signal extinction ratio control method for supplying a control signal to a driving section for performing driving by
10 supplying a laser diode with a bias current and a modulation current, comprising:

a measurement step for measuring average optical power for each burst of the laser diode;

a modulation current control step for controlling a
15 modulation current I_m of the laser diode based on the average optical power measured by the measurement step; and

a bias current control step for controlling a bias current I_b of the laser diode based on the average optical power measured by the measurement step is provided.

20 According to this construction, the constant extinction ratio can be obtained in relation to the high-speed burst signal by signal processing by a software, and the transmission quality is not degraded.

Further, according to the invention, a laser diode
25 drive circuit, comprising:

a bias current source for supplying a laser diode with a bias current;

a modulation current source for supplying the laser diode with a modulation current;

5 a measurement means for measuring average optical power for each burst of the laser diode;

a modulation current control means for controlling a modulation current I_m of the laser diode based on the average optical power measured by the measurement means; and

10 a bias current control means for controlling a bias current I_b of the laser diode based on the average optical power measured by the measurement means, wherein

the average optical power and an extinction ratio of the laser diode become constant is provided.

15 According to this construction, the constant extinction ratio can be obtained in relation to the high-speed burst signal at a small cost, and the transmission quality is not degraded.

In the invention, the modulation current is slightly
20 changed in units of burst, and the constant extinction ratio is maintained by a variation of the optical output power thereby changed. The method wherein an alternate current is superimposed on a modulation current is equal to adding noise to a signal, leading to degradation of the transmission
25 quality. Meanwhile, in the invention, direct currents are

sort of superimposed, and therefore the transmission quality is not degraded. Further, signal amplitude is slightly changed for each burst in the invention. However, a receiver for burst generally performs gain control for each burst. Therefore, such slightly change of signal amplitude does not cause problems.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing an embodiment of a control circuit of the invention;

FIG. 2 is a flowchart showing a process flow in an embodiment for realizing the control circuit of the invention by a software;

FIG. 3 is a graph showing characteristics of current I_d versus optical output power P_{out} of a laser diode;

FIG. 4 is a graph showing typical characteristics of the laser diode;

FIG. 5 is a block diagram showing a first construction example of a conventional control circuit; and

FIG. 6 is a block diagram showing a second construction example of a conventional control circuit.

BEST MODE FOR CARRYING OUT THE INVENTION

FIG. 1 is a block diagram showing an embodiment of a control circuit of the invention. In FIG. 1, in addition

to a control circuit 1, a laser diode 112, a modulation current source 115, a bias current source 116, and a monitor photodiode 111 for converting section of light of the laser diode 112 to an electrical signal are shown. During burst
5 output, a switch 113 becomes connected and a bias current I_b is always applied to the laser diode 112. During the burst, in the case that data is "L," only the current I_b is applied to the laser diode 112; meanwhile, in the case that data is "H," a switch 114 becomes connected, and currents I_b and I_m
10 are applied to the laser diode 112. As in the foregoing conventional example, descriptions of the pre-bias operation are omitted. Further, a mark ratio of burst data is herein set to 0.5.

The control circuit 1 in FIG. 1 has a power measuring
15 section 11 for measuring power by a signal from the monitor photodiode 111; storing section 12 for memorizing the value measured at the power measuring section 11 as data; a difference detecting section 13 for detecting a difference between the value measured at the power measuring section
20 11 and a value previously memorized in the storing section 12; a $\Delta Pref$ storage 14 wherein a reference value $\Delta Pref$ is previously stored; a comparing section 15 for comparing an output signal of the difference detecting section 13 with the reference value $\Delta Pref$; a modulation current (I_m) setting
25 section 16 for setting a modulation current I_m according to

an output signal of the comparing section 15; a Pref storage 17 wherein a reference value Pref is previously stored; a comparing section 18 for comparing an output signal of the power measuring section 11 with the reference value Pref; 5 a bias current (Ib) setting section 19 for setting the bias current Ib according to an output signal of the comparing section 18; and a controlling section 110 for controlling these respective sections.

Descriptions will be given of operations of this 10 control circuit with reference to FIGS. 1 and 2. After startup, the control circuit 1 sets the reference values Δ Pref and Pref in the Δ Pref storage 14 and the Pref storage 17 respectively. Subsequently, initial values of the modulation current Im and the bias current Ib are set in the 15 modulation current setting section 16 and the bias current setting section 19 respectively. Details of these setting operations are omitted.

When a first burst #1 is transmitted, the power measuring section 11 measures average optical power of the 20 burst based on a signal from the monitor photodiode 111. The result thereof is once memorized in the storing section 12. After that, the modulation current setting section 16 increases the modulation current, by, for example, a current Δ Im equivalent to 1% of the present modulation current Im. 25 While a next burst #2 is transmitted, the power measuring

section 11 measures average optical power of the burst. After that, the difference detecting section 13 detects a difference between the measured average optical power and a value previously memorized in the storing section 12. The
5 comparing section 15 compares this difference with the reference value $\Delta Pref$. When the difference is larger than $\Delta Pref$, the modulation current setting section 16 decreases the modulation current I_m by a specified amount A. On the contrary, when the difference is smaller than $\Delta Pref$, the
10 modulation current setting section 16 increases the modulation current I_m by the specified amount A.

In a next burst #3, an output of the power measuring section 11 is compared with the reference value P_{ref} at the comparing section 18. When the measured power is larger than
15 P_{ref} , the bias current setting section 19 decreases the bias current I_b by a specified amount B. On the contrary, when the measured power is smaller than P_{ref} , the bias current setting section 19 increases the bias current I_b by the specified amount B.

20 It is not necessary to perform these processes for the continuous bursts if these processes are frequent enough in relation to a rate of characteristics change of the laser diode. That is, it is possible that there are some bursts between any of the bursts #1, #2, and #3 that do not contribute
25 to the control in FIG. 2.

The reason why a constant extinction ratio can be obtained by the foregoing operations will be described by using FIG. 3. FIG. 3 shows characteristics of current I_d versus optical output power P_{out} of the laser diode. When
 5 data is "L," it is formulized as follows:

$$I_d = I_b$$

Then, optical output power is P_L . When data is "H," it is formulized as follows:

$$I_d = I_b + I_m$$

10 Then, optical output power is P_H . When a mark ratio is 0.5, it is formulized on average as follows:

$$I_d = I_b + I_m / 2$$

Then, optical output power is P_{ave} .

Here, when the modulation current is increased by ΔI_m ,
 15 it is formulized on average as follows:

$$I_d = I_b + (I_m + \Delta I_m) / 2$$

Then, optical output power is P_{ave+} . An increment of the power then is set to ΔP .

Based on the foregoing formulas, an extinction ratio
 20 ExR is obtained. Characteristics in a linear region of the laser diode can be regarded as a line. The formula thereof is expressed by

$$P_{out} = K \times I_d + J$$

Then, as evidenced by FIG. 3, slope K is expressed by

25 $K = \Delta P / (\Delta I_m / 2)$

The average optical power is expressed by

$$P_{ave} = K(I_b + (I_m/2)) + J$$

Further, it is formulized as follows:

$$P_L = K \times I_b + J$$

$$5 \quad P_H = K(I_b + I_m) + J$$

Therefore, it is formulized as follows:

$$ExR = P_H / P_L$$

$$= (P_{ave} + (\Delta P \cdot I_m / \Delta I_m)) / (P_{ave} - (\Delta P \cdot I_m / \Delta I_m))$$

Here, where ΔI_m is a value proportional to I_m , that is, C
 10 $\times I_m$ (C is a constant number), it is formulized as follows:

$$ExR = P_H / P_L$$

$$= (P_{ave} + (\Delta P / C)) / (P_{ave} - (\Delta P / C))$$

It is understandable that the constant extinction ratio can
 be maintained if control is made so that the average optical
 15 power P_{ave} and the fluctuating amount ΔP of the average
 optical power when the modulation current are changed become
 constant.

This control circuit can be realized by using separate
 sections. Further, the whole or a part of the control
 20 circuit can be realized by using an integrated circuit.

In the foregoing embodiment, descriptions have been
 given on the assumption that the respective sections operate
 under the control of the controlling section 110. However,
 it is also possible that these processes are performed by
 25 a software in the form that an output of the monitor

photodiode 111 is AD-converted, which is taken into a CPU (central processing unit). A process flow in this case is as shown in FIG. 2. That is, in Step S1, reference values $\Delta Pref$ and $Pref$ are respectively set. In Step S2, initial values of a modulation current I_m and a bias current I_b are respectively set. Next, in Step S3, a first burst is transmitted. In Step S4, average optical power of the burst is measured based on a signal from the monitor photodiode 111. The result thereof is memorized in Step S5. After that, in Step S6, the modulation current is increased by, for example, a current ΔI_m equivalent to 1% of the present modulation current I_m . Next, in Step S7, a next burst is transmitted. In Step S8, average optical power of the burst is measured.

After that, in Step S9, a difference between the value previously memorized and the presently measured value is detected. In Step S10, this difference is compared with the reference value $\Delta Pref$. When the difference is larger than $\Delta Pref$, the modulation current I_m is decreased by a specified amount A and ΔI_m in Step S11. On the contrary, when the difference is smaller than $\Delta Pref$, the modulation current I_m is increased by the specified amount A and decreased by ΔI_m in Step S12. The reason why the modulation current I_m is decreased by Δm in Steps S11 and S12 is to recover the modulation current to an original value by decreasing the

modulation current by ΔI_m increased in Step S6. When Step S11 or Step S12 is finished, a burst is transmitted in Step S13. In Step S14, average optical power is measured. The measured value is compared with the reference value P_{ref} in
5 Step S15. When the measured power is larger than P_{ref} , a bias current I_b is decreased by a specified amount B in Step S16. On the contrary, when the measured power is smaller than P_{ref} , the bias current I_b is increased by the specified amount B in Step S17.

10 After Step S16 or S17, the flow is returned to Step S3, and thereafter, Steps S3 to S16 or S17 are repeated. That is, Steps S3 to S11 or S12 and Steps S13 to S16 or S17 are executed alternately.

15 INDUSTRIAL APPLICABILITY

As described above, according to the invention, direct currents are sort of superimposed. Therefore, a transmission quality is not degraded. In the invention, a signal amplitude is slightly changed for each burst.
20 However, since a receiver for burst generally performs gain control for each burst, this slight change of signal amplitude does not cause problems. Therefore, the invention can be utilized for a burst signal extinction ratio control circuit for controlling an extinction ratio of a laser diode
25 used in optical transmission of digital data in packet

communications and an integrated circuit thereof, a burst signal extinction ratio control method, a computer program, a laser diode drive circuit and the like.